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This paper provides a brief introduction to the problem domain of terrain analysis and outlines the evolution of the CAPIR program emphasizing the special requirements for an effective man-machine interface. The application of current CAPIR technology to typical terrain data capture problems is discussed with selected examples of technology transfer and examples of new commercial photogrammetric instrumentation incorporating graphic superposition capabilities.

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A review of computer-assisted photo interpretation research at USAETL

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Abstract

A program in computer-assisted photo interpretation research (CAPIR) was initiated at the U.S. Army Engineer Topographic Laboratories (USAETL) in 1979. The primary objective was to develop and implement concepts to increase the productivity of the human photo interpreter tasked with extracting terrain data from aerial imagery. Early efforts focused on implementation of interactive software for direct capture of digital map data from stereo mapping and reconnaissance photography. The development of a hardcopy stereo workstation with integral computer graphic superposition has been essential to provide a suitable interactive, closed-loop environment for the photo interpreter.

This paper provides a brief introduction to the problem domain of terrain analysis and outlines the evolution of the CAPIR program emphasizing the special requirements for an effective man-machine interface. The application of current CAPIR technology to typical terrain data capture problems is discussed with selected examples of technology transfer and examples of new commercial photogrammetric instrumentation incorporating graphic superposition capabilities.

Opportunities to extend CAPIR concepts to softcopy terrain analysis based on adaptation of digital image processing technology are then presented. Digital image source materials and potential softcopy processing advantages are discussed and key requirements for effective softcopy terrain analysis are summarized.

The problem domain of terrain analysis

Analysis of aerial photography and collateral data to characterize various components of the terrain in greater detail than depicted on standard topographic maps or to address specific environmental problems is well-known. Terrain analysis can support such sensitive environmental activities as site selection, forest and wildlife management and highway planning; terrain analysis is critical to military planning requirements associated with site selection, mobility, route planning, intervisibility, cover and concealment. Typically, the primary source material for terrain analysis is conventional stereoscopic mapping photography. Many attempts have been made to automate all or part of the terrain photo interpretation process, but the analyst of choice is still a skilled human photo interpreter trained in a relevant natural science discipline who is familiar with the geographic region under study. The conventional terrain analysis product is a set of specialized map overlays, often distributed as mylar overlays registered to the corresponding topographic base map, characterizing vegetation, drainage, soils, landforms, slope, transportation and culture. Although contemporary standard products, such as the Defense Mapping Agency (DMA) Planning Terrain Analysis Data Base (PTADB) and Tactical Terrain Analysis Data Base (TTADB) are generally distributed in hardcopy media, a rapid transition to digital representation of terrain data for production and dissemination is underway in both the military and civil sectors.

The fundamental difficulties associated with terrain analysis have not yielded readily to modernization. There has been a continuing shortage of experienced photo interpreters for operational terrain analysis; recruiting, training and maintaining high quality interdisciplinary teams has been particularly difficult. The data extraction and cartographic preparation processes are labor-intensive. The shift to production of digital products has been implemented in an incremental fashion based on digitization of photo interpreter generated manuscripts followed by interactive editing. Unfortunately, these changes have provided no additional support to the analyst; instead, a series of fragmented processes have been placed in production that introduce significant metric degradation and compilation errors that can be difficult to detect and are often expensive to rectify.

The computer-assisted photo interpretation research program

Concepts for a program in computer-assisted photo interpretation research (CAPIR) were formulated at USAETL in 1979 under an Independent Laboratory In-House Research (ILIR) study. The goal was to develop interactive environments for the expert photo interpreter to increase both productivity and metric accuracy in extracting digital terrain data from aerial imagery. An early decision was made to maintain a rigorous geodetic frame of reference as a basis for diverse spatial data integration and to support multi-sensor image exploitation. Concepts and initial efforts of the CAPIR Program are described in a previous paper (Lukes, 1981).

Baseline CAPIR objective

The CAPIR program has emphasized the development of technology to support interactive extraction of digital terrain data from stereo aerial photography. Here, the typical media is 23 x 23 cm film transparencies acquired with modern mapping camara at scales from 1:10,000 to 1:100,000. Initial efforts were based on the adaptation of advanced photogrammetric equipment, specifically analytical plotters, to photo interpretation tasks. These modern mapping instruments support real-time computation of three-dimensional (3d) ground coordinates from photo measurements made in the stereo model. Although analytical plotters were conceived and designed as high precision instruments to perform elevation extraction, a computer scientist might recognize their functionality as three-dimensional digitizers generating 3d spatial data streams similar to the two-dimensional data streams from conventional digitizing tablets.

Prototype CAPIR stereo hardcopy workstation

A preliminary CAPIR capability was implemented at the USAETL Research Institute by interfacing an APPS-IV analytical plotter (Greve, 1980) with a geographic information system based on the Analytical Mapping System (AMS) software (Pywell and Niedzwiadek, 1980). The fundamental innovation in development of the stereo hardcopy workstation was the successful integration of real-time graphics display within the stereo optical train (Greve et al, 1981). An initial single-channel graphics system was upgraded to a support dual-channel stereo graphics with an improved binocular optical system (Greve, 1983). The capability for graphic "superposition" provides essential feedback of encoded spatial data to the photo interpreter essential for on-line analysis. In addition, superposition provides significant tools for effective quality control, revision and intensification of digital map databases.

To date, CAPIR technology demonstrations have focused primarily on frame aerial photography obtained with both metric and non-metric cameras. Capabilities to handle other sensor types have been demonstrated including exploitation of panoramic (optical bar camera) photography and synthetic aperture radar. On-line triangulation software was implemented for each sensor type to recover the acquisition parameters for individual images. In addition, routine procedures to use the DMA Point Positioning Data Base (PPDB) have been implemented.

Implications of CAPIR hardcopy stereo workstations

Although hardcopy stereo workstation technology continues to evolve, the experience to date warrants certain generalizations. Providing a direct link between the photo interpreter exploiting stereo imagery and encoded digital terrain data eliminates many intermediate processes associated with digitization of manuscripts, minimizes opportunities for the introduction of errors and blunders while supporting on-line verification. Use of photogrammetric techniques leads to dramatic improvements in metric accuracy and creates a framework for implementation of rigorous mensuration tools. Graphic superposition provides essential feedback to the photo interpreter and critical tools for digital map data maintenance and revision.

Applications of CAPIR technology

Selected investigations pursued in the CAPIR laboratory at USAETL serve to illustrate the potential of this approach. Early investigations pioneered the assessment of previously compiled digital feature and elevation data using graphic superposition. Improved techniques for military point positioning were also demonstrated. Various applications of CAPIR technology to civil works applications were evaluated and several demonstration projects were conducted (Peroutky, 1983). An initial terrain study performed on the Fort Belvoir, VA Quandrangle was reported by Edwards (1985). The CAPIR hardcopy stereo system has been used to generate a high resolution digital terrain data base in support of the Autonomous Land Vehicle Demonstration under the DARPA Strategic Computing Program (Edwards et al, 1986). More recently, the CAPIR system played a novel and significant role in the investigation of the December, 1985 crash of an Army chartered DC-8 aircraft in Gander, New Foundland (Rinker et al, 1987).

Transfer of CAPIR technology

Although much remains to be accomplished in computer-assisted photo interpretation research, concepts pioneered in this research program have led to several developments and considerable technology transfer. Initial military applications include advanced mission planning and tactical point positioning; an active training program has been established at the Defense Mapping School. Concepts of on-line data capture and graphic superposition are key components of the on-going DMA Modernization Program for advanced feature and terrain analysis. Within USAETL, the CAPIR laboratory serves as a testbed for the new Army Terrain Analysis Center modernization initiative.

In the civil sector, CAPIR technology is used operationally to support the National Wetlands Inventory and other activities of the U.S. Fish and Wildlife Service. Operational investments have also been made by the Corps of Engineers Omaha District and the U.S. Bureau of Reclamation in Phoenix.

Commercial hardcopy stereo workstation development

As a researcher, it has been gratifying to participate in the evolution of capabilities for computer-assisted photo interpretation, and to witness the incorporation of increasingly sophisticated graphic superposition capabilities as standard options in commercial photogrammetric instrumentation. Some of the significant commercial developments include the following:

* Autometric APPS-IV Analytical Plotter (monochromatic/stereoscopic graphic superposition);
* Intergraph Intermap Analytic Stereo Plotter (color/monoscopic graphic superposition);
* Kern DSR-11 Analytical Plotter with MAPS 350 (color/monoscopic graphic superposition);
* Wild S9-AP Analytical Plotter (monochromatic/stereoscopic graphic superposition);
* Zeiss Video-Map Analytic Plotter System (monochromatic/stereoscopic graphic superposition).

To date, engineering approaches adopted for stereoscopic superposition have made use of small monochromatic cathode ray tubes (typically green phosphor 7" CRTs). Implementation of color superposition, preferred for display of complex feature data, has required use of much larger CRTs and has been implemented only in single channel (monoscopic) graphics display systems.

Related on-going developments at USAETL

Selected aspects of the CAPIR program have been adopted by the USAETL Geographic Sciences Laboratory for integration in field demonstration systems. The Terrain Analyst Workstation (TAWS) has been developed to permit demonstration and evaluation of advanced concepts for digital terrain analysis with Field Army Terrain Analysis Detachments. At this time, TAWS demonstrations have been conducted at a series of sites in the United States, Europe and the Pacific in conjunction with operational activities or major training exercises. A second demonstration system in support of the AirLand Battlefield Environment (ALBE) Program is currently under development.

A 1986 reorganization of USAETL led to the transfer of CAPIR personnel and laboratory from the Research Institute to the Topographic Developments Laboratory as the basis of an expanded initiative in digital terrain database construction and maintenance. The immediate program objective is reimplementation of the AMS software on Unix-based engineering workstations networked in a distributed system. Development of a Light Table Evaluation System (LTES) as another specialized hardcopy monoscopic workstation is underway concurrently. The third near-term activity is the extension of the existing softcopy workstation, a VICOM digital image processor currently functioning as a softcopy stereo comparator, into a softcopy analytical plotter fully supported by AMS software. The following discussion introduces some of the key issues surrounding softcopy terrain analysis.

Potential for softcopy exploitation

In recent years, great emphasis has been placed on the direct analysis of digital imagery using CRT-based digital imaging processing (softcopy) systems. Two areas of particular activity include the interactive exploitation of near-real-time imagery and automated image analysis via statistical pattern recognition. Although acceptance of this new technology has been slow in many application areas, dramatic reductions in cost and improved performance are now being experienced that have greatly expanded interest in softcopy image exploitation (Blanchard, 1987; Upton, 1987).

Terrain analysis from digital imagery

There are several natural advantages to softcopy image exploitation for terrain analysis. Advances in image acquisition system technology has resulted in a variety of near-real-time sensors operating from airborne and spaceborne platforms with on-board recording and/or real-time electronic data links to ground stations. Some of the existing sensors of potential value to terrain analysis include the Landsat multispectral scanner (MSS) and Thematic Mapper (TM), SPOT multispectral and stereo panchromatic electro-optical sensors and synthetic aperture radar (SAR) from systems such as the NASA Shuttle Imaging Radar (SIR-B) or the Intera STAR-1. It is conceivable that a single softcopy system could be designed with multi-image window displays to support exploitation of imagery acquired from such a diverse set of sensors supported by embedded photogrammetric and radargrammetric routines operating transparent to the analyst.

Other potential advantages include simplified stereoscopic exploitation with automatic stereomodel set-up and maintenance, introduction of interactive compilation tools (Pentland, 1987), flexible display of diverse collateral data, integration of interactive "consultant" modules (Duda and Garvey, 1980) and electronic dissemination of terrain analysis products. Finally, softcopy exploitation provides an environment for the integration of autonomous or semi-autonomous knowledge-based computer vision modules (McKeown, 1984; Leighty, 1987).

Requirements for softcopy terrain analysis

Considerable effort will be required to implement optimized softcopy image exploitation systems tailored to terrain analysis. One of the greatest barriers to date has been the overhead associated with the storage, processing and display of large multispectral or stereoscopic panchromatic images (4096 x 4096 pixels/image or more) with interactive capabilities for overview, roam and vector digitization. Effective high-resolution stereo image displays represent a difficult challenge where new technologies are finally becoming available (McAllister and Robbins, 1987). Implementation of photogrammetric and radargrammetric constraints are necessary to support automatic maintenance of the stereomodel, real-time computation of 3d ground coordinates and graphic superposition. Automated stereo correlation capabilities, developed for compilation of digital elevation models, need to be adapted to support delineation of 3d feature data. Finally, well-engineered software will be required to provide an environment conducive to the integration of such experimental software modules as suggested above.

Summary

This paper has surveyed the major objectives and accomplishments of a research program in computer-assisted photo interpretation for terrain analysis at the U.S. Army Engineer Topographic Laboratories. Here, the requirements of the problem domain dictate the essential characteristics of the man-machine interface. The CAPIR program pioneered the concept of on-line computer-assisted photo interpretation adapting photogrammetric instrumentation to permit data capture in a three dimensional ground coordinate system. Electronic graphic superposition within an analytical plotter was developed to provide immediate spatial feedback to the photo interpreter. Typical applications, examples of technology transfer and new commercial developments have been outlined. The potential to extend these concepts to softcopy terrain analysis adapting digital image processing technology has been suggested and some specific requirements of this problem domain were summarized.

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